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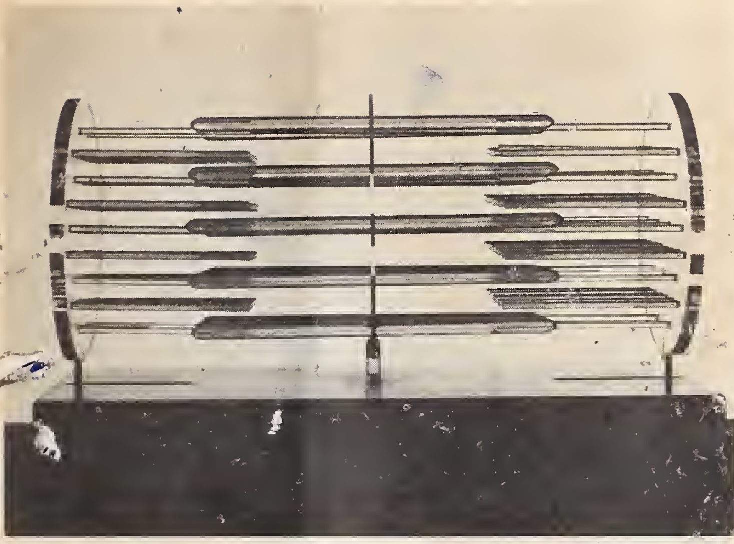

MUSCLE:
Dynamics of Contraction

A 16mm Sound Film, 21 Minutes

A film from Unit IV
Physiology
EBE BIOLOGY PROGRAM

JUNIOR HIGH SCHOOL
SENIOR HIGH SCHOOL
COLLEGE AND ADULT GROUPS

In collaboration with
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OBJECTIVES

- To introduce three types of muscle: smooth, cardiac, and skeletal.
- To establish how the speed and strength of muscle contraction can be regulated.
- To show the internal structure of muscle cells.
- To demonstrate that the contractile properties of a whole muscle can be explained in terms of the properties of single muscle cells.
- To explain muscle contraction using a sliding filament hypothesis.

SUMMARY OF CONTENT

The brain, usually considered the highest organ in the body, must have a means of expressing what goes on inside it. And whether these thoughts are expressed in speech, writing, or artistically in painting or music, it it always through muscles that this expression is brought about.

There are many hundreds of muscles in the body. Some may be small like the muscles adjusting and positioning the eyes; others are very large, like the long muscles in the thigh. Muscles differ greatly with respect to the speeds at which they shorten. In this way they can be divided into three major categories: smooth, cardiac, and skeletal.

Smooth muscles contract slowly and sometimes rhythmically. They are called involuntary because they are not under conscious control. They are spoken of as smooth because of their plain, spindle-shaped appearance in the microscope.

The second type of muscle cells are found in the heart. They show in the microscope a striped appearance, but like the involuntary muscle the heart also contracts automatically; it has its own rhythm.

The third type of muscle, the voluntary or skeletal muscles, are attached to the bones of the skeleton, usually on both ends. It is with their help that we move ourselves through our external environment.

In this film, extensive laboratory demonstrations, cine-photomicroscopy, and rare electronmicrographs are used to reveal that the contractile properties of the whole muscle can be explained in terms of the properties of the single muscle cell, the basic unit of contraction.

VOCABULARY FROM THE NARRATION

myology	involuntary or smooth muscle	striation
myosin	heart or cardiac muscles	striated muscle
actin	voluntary or skeletal muscle	cross section
fiber	longitudinal section	cross-bridge
fibril	mechanisms of contraction	filament

QUESTIONS & TOPICS FOR DISCUSSION

Discuss the following questions before viewing the film:

1. Discuss the degree to which we depend upon muscular activity when attempting to express thoughts or emotions.

2. Briefly survey students' present understanding of the characteristics of muscle contraction. A discussion of this type will likely elicit comments about a) voluntary and involuntary muscle contraction, and, b) muscle contraction variability with respect to strength and speed.

3. Obtain student reactions to a hypothetical muscle contraction hypothesis (perhaps a "coiling fiber" or "stretching fiber" hypothesis) as a means to introduce criteria for evaluating any muscle contraction hypothesis. An acceptable muscle contraction hypothesis must: a) explain the fact that both strength and speed of muscle contraction can be varied, and b) be based upon our current understanding of the structural, chemical, and electrical properties of muscles.

4. Have students consider what they might do experimentally to answer the question: How do muscles contract?

Discuss the following questions after viewing the film:

1. Have the students discuss the reason for the change in the strength of contraction as the strength of the stimulus is changed and what this implies about the behavior of single fibers. A single fiber either contracts fully, or not at all. Variations in the strength of contraction is brought about by the total contraction of a greater or lesser number of individual fibers.

2. Refer to the film sequence in which the frog muscle contractions were graphed, and have students consider how the speed of muscle contraction is naturally regulated in living organisms.

3. Reemphasize the characteristics of isotonic and isometric muscle contractions. In the film, Dr. Edman demonstrates two types of muscle contraction: *isotonic,* in which there is significant shortening of the muscle, leading to movement, and *isometric,* in which the muscle meets considerable resistance and cannot shorten significantly, leading to tension.

4. Discuss the explanation given in the film of muscle contraction in terms of those previously developed criteria for evaluating any muscle contraction hypothesis. This should help emphasize that the explanation in the film could be made more complete if factors in addition to structure and external electrical stimulation were considered.

RELATED EBE MATERIALS

Other 16mm Films in Unit IV, EBE Biology Program

THE BLOOD
THE EARS AND HEARING
EYES AND SEEING
FUNDAMENTALS OF THE NERVOUS SYSTEM
MUSCLE: CHEMISTRY OF CONTRACTION
MUSCLE: ELECTRICAL ACTIVITY OF CONTRACTION

8mm Films

NERVE ACTION—Reflex Arc

FILM CONTINUITY

*Leader—7′**

EB Logo—10′

Titles—17′

1. *Montage: man working out on parallel bars; woman on parallel bars—44′*

Credits—58′

2. *Sequence: view of laboratory; lab technicians; man using sliderule; view of books in library; view of Dr. Mommaerts—91′*

NARRATOR: The department of physiology at the University of California at Los Angeles . . . Here, intensive research is being carried out in many areas of human physiology. Among these areas is myology, the study of the muscular system. Scientists from many parts of the world have been attracted to this research community by its extensive facilities. Heading the research community is a man who has devoted his professional life to the study and teaching of muscle physiology, Dr. Wilfred Mommaerts.

3. *Sequence: Dr. Mommaerts sitting at desk, talking to viewers; view of hand typing; child coloring, hand writing music—124′*

DR. MOMMAERTS: We are studying muscle because the seemingly simple mechanism of its contraction is so very intriguing and so very important. It is important because it is through the single contraction, multiplied hundreds or many thousand-fold, that human life is possible and becomes what it is. The expression of thought is particularly important . . . because while we might say that the brain is the highest organ in the body, without means of expressing its thoughts, we would never know what goes on inside it. And whether we express these thoughts in speech or in writing or by artistic expressions in painting or music or other, it is always through muscles that this expression is brought about.

4. *Sequence: Dr. Mommaerts standing by model human being; designating different muscles on the model; view of man running, focus on leg muscles; Dr. Mommaerts sits by model—150′*

There are many hundreds of muscles in the body. Some may be small like the muscles adjusting and positioning the eyes; others are very large, like the long muscles in the thigh which enable us to perform extensive motions and exert a great deal of power. Muscles differ greatly with respect to the speeds

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*To order replacement footage for damaged portion of film, refer to the scene numbers and 16mm footage in this continuity. Example of footage order: *MUSCLE: DYNAMICS OF CONTRACTION,* scenes 3 through 5; after the 91′ point (end of scene 2), print the next 90 feet.

at which they shorten. In this way they can be divided into three major categories: the first group among these are found in many organs of the internal environment.

5. ***Sequence: views of smooth muscles moving; view of blood vessels; view of Dr. Mommaerts talking; view of more muscles under the miscroscope—181′***

They are very slow in their contraction and they are called the involuntary or smooth muscles. Smooth muscles contract slowly and sometimes rhythmically. We find them in the digestive tract where they cause the slow motions of the intestines which are essential for the digestion and uptake of food. They make up part of the walls of all blood vessels where they help regulate the blood flow. They are called involuntary because they are not under conscious control. They are called smooth because of their plain, spindle-shaped appearance in the miscroscope.

6. ***Sequence: view of Dr. Mommaerts; view of heart muscle cells under miscroscope; view of beating heart; view of model heart; views of athletes, focus on leg muscles; athlete throwing a discus—220′***

The second type of muscle cells are those which make up the heart. Unlike the smooth muscle fibers, they show in the microscope a striped appearance but like the involuntary muscle the heart also contracts automatically; it has its own rhythym. The contractions of the heart are faster than those of smooth muscles. The third kind of muscles and probably the most familiar group are the voluntary or skeletal muscles. These are attached to the bones of the skeleton, usually on both ends. It is with their help that we can move ourselves through our external environment. These muscles are under voluntary control; their motions may be simple or very complex, and may involve little energy or a great deal.

7. ***Sequence: Dr. Mommaerts sitting at the desk; Dr. Howell working in the lab; Dr. Howell sitting at the desk; talking—252′***

As in all life phenomena, the events in muscle are very complex. Many things enter into it. We would like to have some basic questions answered. For example, what switches the contraction on and off, and what is the mechanism of the muscle's action. In short, how does it contract?

Dr. Howell: In order for muscle contraction to be effective, it must be regulated or controlled. This is true with all three kinds of muscle. So we have a point from which to begin. First, what causes muscle contraction, and secondly, how is the strength of muscle contraction regulated?

8. ***Sequence: frog stretched out on the lab table; Dr. Howell stimulating the frog's muscle with an electrical probe—286′***

We have here an anesthetized frog. What we've learned about frog muscles is true in a general way for muscles of other animals, including man. And what we've learned about voluntary muscle is true in a general way about cardiac muscle and smooth muscle as well. I'm now going to expose one of the muscles of the lower leg and its associated nerve so we may see its behavior. Muscles can be made to contract by stimulating the nerves with electric shocks.

9. ***Sequence: probe at frog's muscle with electrical equipment; view of tissue baths; Dr. Howell sitting at lab desk pointing out equipment; graph recording reactions of muscle—322′***

Electric shocks set up nerve impulses which signal the muscle to contract. We can make the muscle contract, however, by stimulating it directly with an electric shock. Now, in order to study muscle more carefully, it is generally convenient to take the muscle out of the animal and to place it in an isolated tissue bath. Now, here we have a muscle connected through this device to the recorder in such a way that we can see the contraction of the muscle. Now let me stimulate the muscle with electric shocks as we did before. These responses are called twitches.

10. ***Sequence: Dr. Howell sitting at desk; view of athlete throwing discus; athlete running; Dr. Howell turning knob; view of graph recording—361′***

Now clearly, in the living body our muscles don't contract with twitches. Our movements are smooth and sustained. Now, we can make our isolated muscle contract with a smooth and sustained contraction by giving it a series of electrical stimuli and giving the stimuli close together. As I increase the frequency of electrical shock, the responses come closer and closer together until they converge into a smooth contraction. As we slow down the frequency of the stimulation, we can see once again the individual twitches.

11. ***Sequence: Dr. Howell turning knob; view of graph recording; Dr. Howell talking—389′***

Now there is another property of skeletal muscle which we can see with our isolated muscle, and that is, if we change the intensity of stimulation we will change the strength of the contraction that results. Now you've seen that as we increase the strength of the electrical shocks we increase the strength of the contraction. But just why is that? In order to answer that question, we first have to look at the internal structure of the muscle.

12. ***Sequence: view of muscle, probes pointing out specific parts; muscle being separated into two parts; view of graph recording reactions; closeup of one fiber—429′***

So the muscle is really made up of many individual strands of fibers. This fact explains why the strength of muscular contraction varies with the strength of the stimulus. When a weak stimulus is applied, only a few fibers are activated and the muscle contracts weakly. When a stronger stimulus is applied, more fibers are activated and the muscle contracts more strongly. If a very strong stimulus is applied, all of the fibers are activated, and the muscle contracts with its maximum strength. The question now is—are the properties of the individual fibers the same as the properties of the whole muscle?

13 ***Sequence: Dr. Edman looking through microscope; view of the fiber in test plate; probes taking fiber apart; view through microscope—463′***

Dr. Edman: I'm just finishing up the dissection of the single fiber, and I have here now a single cell which is just as it used to be in the intact muscle. You may ask why we take the trouble to dissect a single fiber. Well, the single fiber is the basic unit of contraction and in order to learn about the mechanism of contraction we have to go down to this level. I am now freeing it from its connections to transfer it over to the special trough. This is a rather tricky operation. You cannot touch the fiber the least because then it will be damaged.

14. ***Sequence: Dr. Edman taking the fiber out; mounts it on slide; looking through microscope; view of fiber being stimulated by probes; view of athlete running; a hand writing—490′***

I have now mounted the fiber between a light movable lever and a device by which I can record the mechanical behavior of the fiber. I'm now going to stimulate the fiber. The fiber shortens. This is equivalent to what happens when you are walking or running, or writing. I have now immobilized the fiber by putting a stop in front of the lever.

15. ***Sequence: view of fiber being stimulated by probe; view of man's arm with muscles straining; Dr. Edman looking through microscope; closeup of fiber—521′***

When I now stimulate the fiber it is not able to shorten appreciably. This is equivalent to what happens when you clench your first or when you're arm wrestling, or when you try to lift a very heavy load. The individual muscle fiber is the basic unit of contraction. But here we must ask ourselves what special structures inside the cell enables it to contract? We are

now looking at the fiber at a relatively high magnification. Notice that there is a definite pattern of light and dark stripes or striations. This is typical of voluntary muscle which is often referred to as striated muscle.

16. Sequence: Dr. Edman; view of muscle fiber; probe making it contract—545′

I am now going to stimulate the fiber again but this time watch the striations. Watch again. And again. The fiber, to be sure, contracts, but more specifically it is the striations which contract. This was something of a mystery until the modern electron microscope was developed.

17. Sequence: view of Dr. Reedy looking through microscope; closeup of muscle through microscope; Dr. Reedy talking; view of muscle—564′

Dr. Reedy: The electron microscope enables us to examine the structure of cells at magnification from about five thousand to five hundred thousand. This enables us to see the finest structures in muscle in detail a hundred to a thousand times finer than that provided by the light microscope. This instrument is used primarily as a camera in order to take photographs of the fine structure.

18. Sequence: view of filing cabinet; equipment; Dr. Reedy sitting at desk talking; showing pictures of muscles; pointing out specific parts—596′

Now these pictures represent thin sections of muscle. This is a picture of rabbit muscle and shows us both sides of this fiber or muscle cell. In this longitudinal section, the most prominent elements are these dense and light cross bands which alternate and produce a segmented structure in the muscle. The banding or segmentation of muscle is even clearer at higher magnification, and here we can also see that the substance within the fiber is split longitudinally by clefts which run between the split-up bundles. These are called fibrils. Between the fibrils these clefts contain tubules and other supporting structures important to the function of the muscle.

19. Sequence: Dr. Reedy showing picture of muscle; pointing out specific parts; showing picture of insect flight muscle—628′

Now at higher magnification yet we can see that these dark bands end rather sharply, and are composed of rather thick filaments or rods running from this border to this border. And we can see that the lighter bands have thinner threads still which run part way into the bundle of thick filaments. If we cut a cross section slicing the muscle this way, we are able to see the fibrils end on. Here again at lower magnification, we're looking at a cross section of insect flight muscle. These gray round objects are the fibrils in cross section.

20. Sequence: an enlargement of a single fibril; pointing out the dots; a further enlargement of single fibril; Dr. Reedy talking—658′

Here is an enlargement of a single fibril and in this fibril we see a very regular hexagonal arrangement. Actually these dots are end-on views of the thick and thin filaments that we saw earlier. Now if we enlarge this further still, to 200,000 times, we see the extreme regularity and elegance in which the filaments are arranged. These filaments each contain several hundred molecules of protein. The thick filaments contain the protein syosin; the thin filaments contain the protein actin. I think it will help our understanding of the three-dimensional arrangement of these structures to look at a model.

21. Sequence: Dr. Reedy showing model; talking; pointing out various parts as he talks—682′

Now if you look at the end of this model, you will see the hexagonal arrangement of thin filaments and thick filaments that we were just describing in the picture. When we come around to the front of the model we get a much better understanding of why the cross striping or cross banding is such a prominent part of muscle structure in longitudinal sections. You can see how the thick filaments are arranged side by side to form the dark bands. The thin filaments are present and define the area of the light bands.

22. Sequence: Dr. Reedy talking; view of model; model contracting, relaxing, lengthening; Dr. Reedy showing another picture of muscle—712′

Now our observations with the electron microscope are really quite interesting because they show that when muscle shortens, the filaments don't shorten. They move; they slide over and past one another, like this: contraction, relaxation, lengthening again. Contraction, relaxation, lengthening again. It's natural to ask what interaction between the thick filaments and the thin filaments could produce this tendency to shorten. Actually that sort of question is really the prime focus of much current research in the structure of muscle. Here you can see individual thick filaments and thin filaments rather clearly separated and defined.

23. Sequence: closeup of muscle; pointer designating different things; Dr. Reedy talking—730′

One of our strongest clues concerns these little side bristles or cross bridges that reach out from the thick myosin filaments towards the actin filaments, and appear as if they were capable of grabbing hold of the actin filaments, going through a ratchet-like motion and then releasing them to repeat the cycles and cause the sliding and consequent shortening. Many of the details of how these finer details behave in muscle remain to be clarified, and many of our ideas about these events are still highly theoretical.

24. Sequence: closeup of muscle fiber; Dr. Reedy looking at microscope; closeup of fiber being probed; woman doing gymnastics on high bar—750′

Narrator: No one can say for sure precisely how the molecules of actin and myosin behave during contraction. Scientists are continuing their research to find out. Certainly, the interaction of these molecules are fundamental to the contraction of each muscle fiber. And it is the contraction of the single fiber multiplied many times that results in the contraction of whole muscles and ultimately in the large variety of movements of the human body.

End titles—764′

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